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Quarterly Highlights of Sandia's Photovoltaics Program

Sandia National Laboratories

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In this issue, module durability research at Sandia is discussed.

How long should a photovoltaic module last? The answer to this question depends on the intended use for the module and on its design and construction. Durability, or service lifetime, may not be a major consideration for modules used in a short-term billboard lighting system, for instance, where the modules may be considered a disposable commodity. However, for building-integrated photovoltaic systems, where the cost of removing or replacing modules is high, the lifetime of the modules is a significant concern. Module durability, along with durability of other components in the system, is a concern for companies participating in programs such as DOE's Million Solar Roofs, the Sacramento Municipal Utility District's PV Pioneer Program, or residential programs sponsored by the California Energy Commission. Similarly, for remote photovoltaic-powered telecommunication systems or residential lighting in third-world countries, module reliability is a significant consideration, again because of the high cost of field maintenance. Utility-scale applications provide the highest economic premium on module durability, where system power production may be specified to degrade in power by no more than 10% in 30 years to meet financial goals. The future growth of the photovoltaic industry depends on these markets with a premium for module durability, and, as a result, 30-year module lifetime has been a goal of the DOE Photovoltaic Program for many years.

Highlighted here is Sandia's research in module durability, which uses new test procedures to identify subtle failure mechanisms that must be addressed to achieve 30-year module lifetimes. We also have in progress well-monitored, long-term outdoor exposure programs in collaboration with several manufacturers to address durability issues. The failure mechanisms being investigated have not been adequately identified by today's accelerated qualification test procedures, indicating a need for improvement in these procedures as well.

Motivation for Module Durability Research

Years of research and development by the photovoltaic industry, universities, and national laboratories such as the Jet Propulsion Laboratory, the National Renewable Energy Laboratory, and Sandia, plus module qualification test standards such as IEEE 61262, UL 1703, and IEC 1215, have brought module technologies to the performance and safety levels indicated by today's product warranties, shown in Table 1. However, field measurements conducted over the last ten years on well-designed and installed systems have indicated power losses attributed to module degradation in the range of 1 to 2% per year. In some systems, personnel safety has also been compromised due to cracking or splitting of module superstrates or backing materials, thus exposing high-voltage circuits to touch. To reach a higher level of module durability, a concerted research effort is required to provide a more fundamental understanding of the failure mechanisms that occur as a result of actual long-term field exposure. The culmination of this work will be the development of improved manufacturing processes or materials that address observed failure mechanisms, taking industry closer to commercial modules with lifetimes of 30 years or more.

Modules are exposed to a wide variety of environmental factors at different sites around the world. Cold Canadian sites, sites in the desert Southwest in the U.S., and hot tropical or coastal sites in Central America all represent different environmental extremes. Daily and cloud-induced temperature variations, ambient temperature, hail, wind, rain/humidity, lightning, thermal cycling, freezing and thawing, and the ultraviolet (UV) content of sunlight all have varying and sometimes synergistic influences on module lifetime. These environments coupled with long-term exposure have proven to be more severe than today's standard accelerated aging tests, resulting in subtle failure mechanisms that limit module lifetime. Many of the long-term degradation mechanisms observed were not identified during the accelerated testing procedures used in developing products and in qualification testing, where products are put through standard test procedures such as IEEE 61262 or IEC 1215, and are then qualified for use. For instance, module delamination observed in some cases in the field had not been observed in qualification tests, nor had solder bond fatigue failures that resulted in localized hot spots (discolorations) on module back sheets. In addition, the severity of specific degradation mechanisms, delamination for instance, has been observed to be both technology and site dependent. As in other industries, there is a gap between reliability information obtained from accelerated aging tests and that obtained from real-time outdoor exposure. Therefore, there is motivation for studying failure mechanisms observed in the field so that accelerated tests better tailored to actual "end-of-life" mechanisms can be developed.

This article summarizes recent collaborative research emphasizing the diagnostic evaluation of commercial modules following long-term (10- to 20-year) field exposure. To date, the work has been oriented primarily to crystalline silicon modules because the newer thin-film module technologies are still in relatively early stages of development and field exposure. Lessons learned will facilitate the development of diagnostic procedures specifically oriented to thin-film modules. The adaptation of diagnostic techniques to thin-film technologies is in progress in preparation for qualified thin-film modules following at least five years of field exposure.

The synergy resulting from a collaborative approach to module durability research has proven to be both productive and cost-effective.

Sponsored by the U.S. Department of Energy, Sandia's research has been significantly enhanced through a teamed effort with the National Renewable Energy Laboratory (NREL), the Florida Solar Energy Center in Cocoa, Florida, and the Southwest Technology Development Institute (SWTDI) in Las Cruces, New Mexico. Plus, direct involvement by U.S. module manufacturers such as ASE Americas, AstroPower, Siemens Solar, Solarex, and United Solar Systems has resulted in specifically focused research of relevance to each manufacturer. As needed, the complementary expertise and analytical capabilities available from Sandia's module durability team have been used to investigate specific degradation mechanisms and to optimize associated manufacturing processes.

Table 1. Limited Warranty Periods for Commercial Modules (Percentage Power Reduction Allowed)

Manufacturer	Technology	Warranty (Years)
ASE Americas	mc-Si	20 (–20%)
AstroPower	c-Si	20 (–20%)
AstroPower	Si-Film	10 (–10%)
BP Solar	c-Si	20 (–20%)
Evergreen Solar	mc-Si	10 (–10%)
Kyocera	mc-Si	12 (–10%)
Siemens Solar	c-Si	25 (–20%)
Siemens Solar	CIS	5 (–10%)
Solarex	mc-Si	20 (–20%)
Solarex	a-Si	20 (–20%)
United Solar Systems	a-Si	20 (–20%)

Durability Information from Field-Aged Modules

As a result of the relatively slow evolution of photovoltaic technology, an additional opportunity now exists for more rapidly improving the lifetime of modules. A large number of qualified modules from established manufacturing facilities have now been in the field for many years, in some cases approaching 20. Detailed investigation of these field-aged modules has resulted in new techniques to identify degradation mechanisms and has provided insight required to optimize manufacturing processes for extended module lifetime. For example, a field survey and subsequent module autopsy were recently conducted on a system installed in Utah in 1979 with modules from four different manufacturers (Figure 1). These modules provided durability information after nearly 20 years of real-time exposure for a variety of module designs, superstrates, encapsulants, cell metallizations, and soldering processes. Lessons learned will be documented during this effort, and a primary emphasis will be to document both degradation mechanisms and success stories. For instance, initial indications are that one of the four manufacturers used cell metallization and soldering processes that have aged very well for 20 years (Figure 2). Understanding the characteristics of these manufacturing processes with proven durability will provide valuable insight for today's manufacturers.

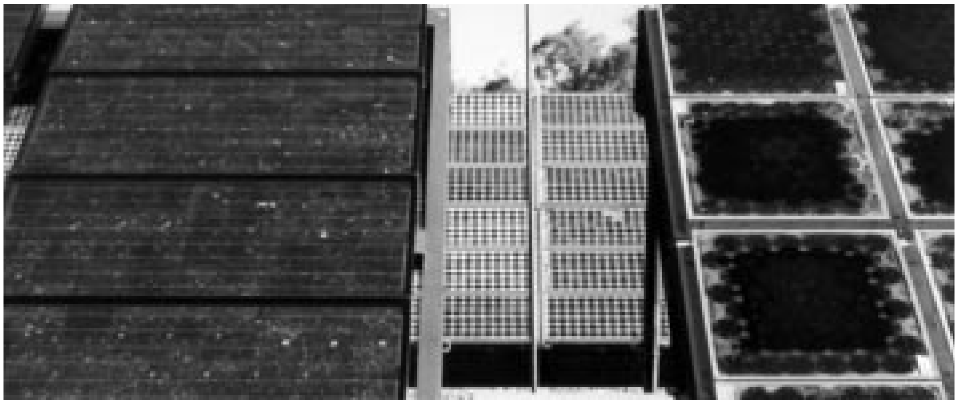


Figure 1. New and 20-year-old module technologies in arrays at Natural Bridges National Monument, Utah.

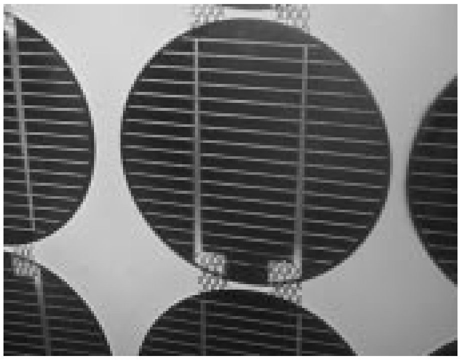


Figure 2. Cell metallization and multi-strand interconnect ribbon have aged well on 20-year-old Spectrolab modules.

Application of Diagnostic Techniques

Until recently, relatively little effort had been made to evaluate the degradation mechanisms in field-aged modules, partially because of the difficulty in dissecting the laminated modules and partially because of the lack of established diagnostic procedures. Progress has been made in both areas. The following sections of this paper briefly describe both destructive and non-destructive procedures that have been applied to different components of field-aged modules, along with illustrative examples. In cross-section (see Figure 3), a typical crystalline silicon module has a superstrate (usually tempered glass), a polymer encapsulant (usually ethylene-vinyl-acetate [EVA]), copper interconnect ribbons, solder bonds, solar cells, and a back sheet (typically Tedlar® or glass).

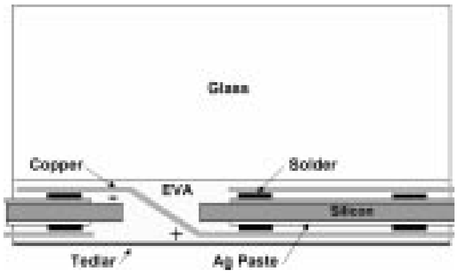


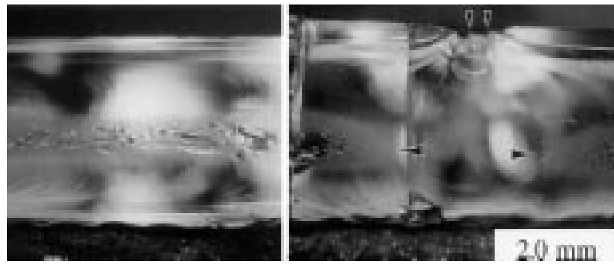
Figure 3. Cross section of a typical crystalline silicon photovoltaic module.

Superstrate Materials

The superstrate used for the front surface of flat-plate photovoltaic modules has typically been tempered, low-iron, rolled sheet glass that is about 3.2-mm thick. AFG Industries and PPG have manufactured most of the sheet glass used for modules manufactured in the United States. The superstrate material serves several purposes in the module: mechanical rigidity, impact resistance, optical transparency, electrical isolation of the solar cell circuit, and outdoor weatherability. Manufacturers of new thin-film photovoltaic modules typically use non-tempered low-iron glass or polymers such as DuPont Tefzel® as the module superstrate material. The mechanical strength and impact resistance of the superstrate are subjected to stress testing through standardized module qualification tests that employ thermal cycling, mechanical loading and twisting, and ice-ball (hail) impact tests. Our investigation of field degradation mechanisms has identified additional characteristics of the superstrate materials that influence field durability.

Impact Resistance

Recent analysis of module breakage in a roof-mounted array identified an impact-induced failure mode best addressed by system designers, rather than by module manufacturers. Historically, an adequate level of impact resistance has been defined in standardized qualification tests as the ability to withstand impact testing using 2.54-cm (1-in) diameter (8 gram) ice balls propelled at 23 m/s (52 mph). Many years of field experience with typical ground-mounted arrays of flat-plate modules with tempered glass superstrates have indicated this criterion was a reasonable compromise between cost and field durability. However, our field investigation, followed by glass fracture analysis and then by impact testing in the lab, confirmed that small (2- to 4-gram) stones propelled in storms to relatively low velocities (10 to 15 m/s) are capable of fracturing the tempered glass in typical modules. Figure 4 illustrates glass cross sections from fractured field samples, and Figure 5 shows the equipment used for laboratory verification. The significance of this finding for designers of roof-mounted systems is that stones (gravel) commonly used as the top covering on commercial and residential roofs must be avoided or stabilized.



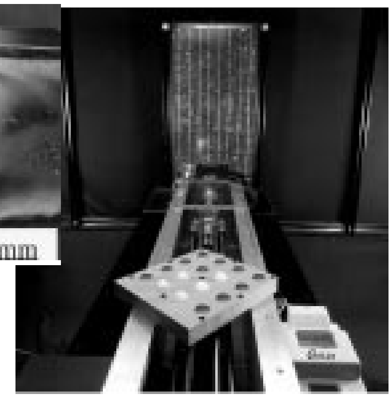


Figure 4. ⇑ Features "frozen" in glass at the instant of fracture provide the information required to diagnose the cause, in this case wind-blown roofing gravel.

Figure 5. ⇒ Equipment used for propelling ice balls or stones into PV modules.

Optical Transmittance

Module superstrate materials should have a high spectral transmittance for all wavelengths of sunlight to which photovoltaic cells in the module respond. However, one important tradeoff has to do with the transmittance of short-wavelength UV sunlight. Typically, the polymer encapsulants used to laminate the superstrate to the solar cells in a module are degraded (discolored) by extended exposure to UV light, and the encapsulant's adhesive properties may be degraded as well. Therefore, it is desirable for the superstrate to prevent UV sunlight (less than 400 nm) from reaching the encapsulant material. Although low-iron glass formulations have varied somewhat over the years, the glass industry has now arrived at formulations that appear to be a good trade-off between encapsulant protection and loss of usable light to the solar cells. To screen out UV light, a small amount of the element cerium (Ce) was added to glass formulations used for photovoltaic modules starting in about 1990.

Spectral transmittance was measured for both new and 1989-vintage low-iron glass typically used for photovoltaic modules and for the Tefzel® polymer also used for some modules. The 1989-vintage tempered-glass sample was extracted from a module exposed in the field for about six years. These transmittance measurements (see Figure 6) suggest that current-vintage glass with the Ce additive are superior to glass formulations used in 1989, from an encapsulant protection (UV screening) perspective. Recent vintage glass with Ce additive provides a significant reduction in the high-energy UV sunlight that reaches the encapsulant in the module. A convenient way for detecting the presence of Ce in glass samples is to illuminate them with a common 375-nm hand-held ultraviolet lamp. If Ce is present in the sample, it will fluoresce a distinctive magenta color, particularly distinctive if the edge of the glass sheet can be viewed while illuminated.

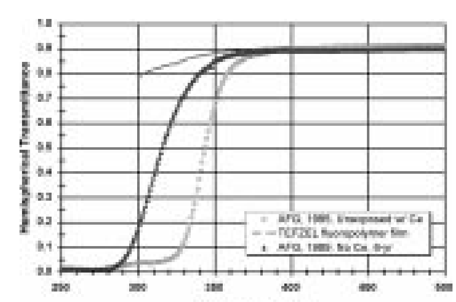


Figure 6. Transmittance of module superstrate materials: AFG tempered glass and DuPont Tefzel®. Cerium additive reduces the harmful ultraviolet sunlight reaching the module encapsulant.

Encapsulant Materials

As does the module superstrate material, the module encapsulant must serve several purposes. The encapsulant's primary purpose is to bond, or laminate, the multiple layers of a module together. Additional encapsulant characteristics must include high optical transmittance, good adhesion to different module materials, adequate mechanical compliance to accommodate stresses induced by thermal expansion, and good dielectric properties (electrical insulation). Over the years, a variety of encapsulant materials has been used in modules including polyvinyl butyral, silicone rubber, ethylene-vinyl-acetate (EVA), and other proprietary encapsulants.

Optical Losses in Encapsulant

For almost 15 years, the dominant encapsulant material in the photovoltaic industry has been EVA. As a result, a significant level of research by industry and by NREL has been aimed at understanding and improving the properties of EVA for application in photovoltaic modules. Particular emphasis has been given to minimizing the propensity of EVA to discolor or "brown" after long-term exposure to ultraviolet sunlight with module operating temperatures often above 50°C. Commercial EVA sheet material, available from STR Corporation, comes in two generic types: "standard cure" (A9918) and "fast cure" (15295), with the fast-cure material having somewhat better UV aging characteristics. A convenient way for highlighting EVA damage is to illuminate the module with a 375-nm hand-held UV lamp. If the EVA has degraded, it will fluoresce over a wide wavelength range looking "white" (Figure 7). Samples of standard-cure EVA have been extracted from field-aged modules in order to measure the optical loss in transmittance (see Figure 8). For modules of this vintage, EVA browning often resulted in module power degradation rates on the order of 1% per year.

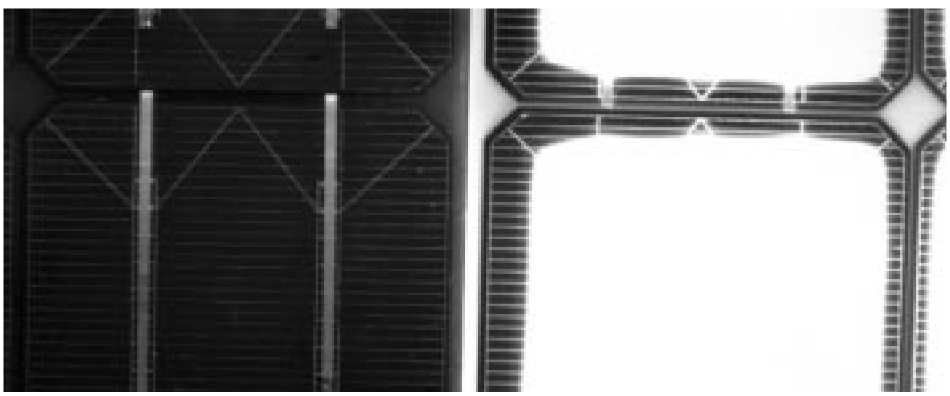


Figure 7. EVA browning patterns highlighted by illumination with 375-nm lamp. Damaged EVA fluoresces producing rectangular regions shown on cells in 1984-vintage module at right. Unexposed cells at left.

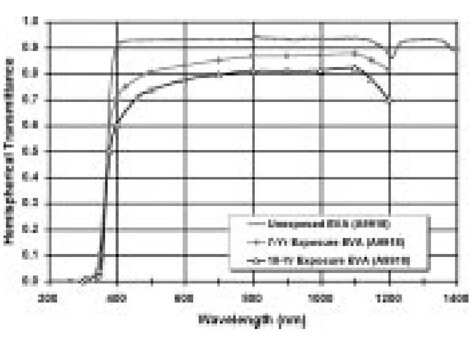


Figure 8. Transmittance loss in EVA samples taken from 1985-vintage modules compared to unexposed EVA. Aged samples were prior to using cerium additive in superstrate glass.

Fortunately, EVA browning losses in modules manufactured today can be greatly reduced for both types of EVA material by using glass superstrates with the cerium additive. The benefit of the Ce-glass with fast-cure EVA has been demonstrated at Sandia on modules continuously exposed for the last eight years. Within our measurement repeatability of ±1.5%, no detectable loss in short-circuit current has been observed to date for these modules (Figure 9). In addition, even though the Tefzel® material previously shown in Figure 6 has very high UV transmittance, initial indications are that its oxygen permeability is high enough that compensating chemical reactions occur, effectively minimizing EVA discoloration.

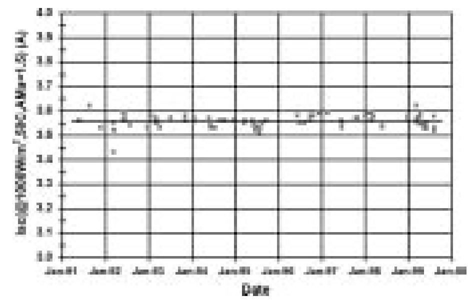


Figure 9. No detectable loss in short-circuit current observed after eight years of exposure in Albuquerque. Module uses AFG Solite® glass with cerium additive with fast-cure EVA encapsulant.

Module Delamination

Module delamination, resulting from loss of adhesion between the encapsulant on other module materials, is a degradation mechanism that needs to be addressed in order to achieve 30-year product lifetimes. From an industry-wide perspective, delamination has occurred in only a small percentage of modules manufactured since the mid-1980s. However, it has occurred to varying degrees in modules from most manufacturers, and because the causes for the failure mechanism are not well understood, it is a continual quality-control concern for manufacturers. Most of the delamination observed in the field has occurred at the interface between the encapsulant and the front surface of the solar cells in the module, although cases with delamination between the encapsulant and the module back sheet have also been documented. A common observation has been that delamination is more frequent and more severe in hot and humid climates, sometimes occurring after less than five years of exposure. Delamination first causes a performance loss due to optical de-coupling of the encapsulant from the cells (Figure 10). Of greater concern from a lifetime perspective is the likelihood that the air void resulting from the delamination will provide a preferential location for moisture accumulation, increasing the possibility of corrosion failures in metallic contacts. Unfortunately, typical accelerated-aging tests have not been effective in accelerating the mechanisms responsible for delamination, making laboratory investigation of the phenomenon difficult.

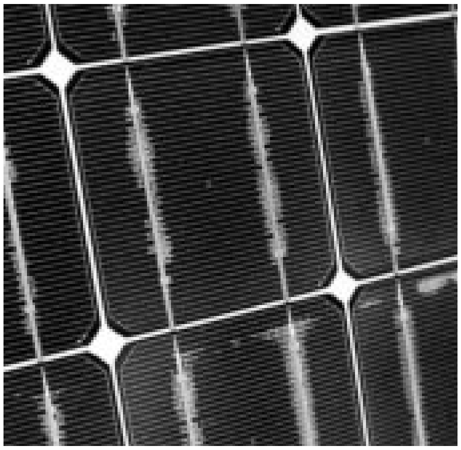


Figure 10. Module delamination resulting from extended field exposure often initially occurs adjacent to cell interconnect ribbons.

In collaboration with module manufacturers, encapsulant manufacturers, and the Florida Solar Energy Center (FSEC), Sandia has developed and applied a new diagnostic technique that has helped identify multiple factors contributing to loss of encapsulant adhesion. Although destructive in nature, the new technique provides the only means available for quantifying encapsulant adhesive strength in field-aged modules and for analyzing the chemical influences contributing to delamination. Field-aged modules were selected for evaluation and mounted on a milling machine. A diamond-grit tool was used to core through the cell material from the back side until contact was made with the module's glass superstrate. A metal screw was bonded to the circular sample using epoxy. Then, the screw was twisted using a torque-measuring tool and the peak torque at adhesive failure was recorded (Figure 11). The peak torque value was used to calculate the peak shear stress when adhesive-failure occurred. Typical measurements for unexposed modules resulted in peak shear stress in the range of 3 to 6 MPa for EVA encapsulant, and greater than 15 MPa for non-EVA encapsulants. After field exposure, this adhesive (shear) strength drops, reaching a value of zero when delamination occurs.

Chemical analyses of dozens of cell and encapsulant samples from field-aged modules have also been conducted by FSEC using Auger electron spectroscopy. By comparing samples from unexposed modules to those from field-aged modules, these chemical analyses provided strong evidence of the dynamic chemical activities occurring in the module during field exposure. For instance sodium deposits are found on the cell surface in field-aged modules, but not in unexposed modules. The only logical source for the reactive sodium element is the glass superstrate, indicating that environmental factors associated with field aging result in sodium migrating through the EVA encapsulant and depositing at the cell surface. Sunlight, temperature, and moisture migration through the encapsulant apparently motivate a variety of chemical reactions, many of which may degrade the integrity of the encapsulant's adhesive bond to the cell.

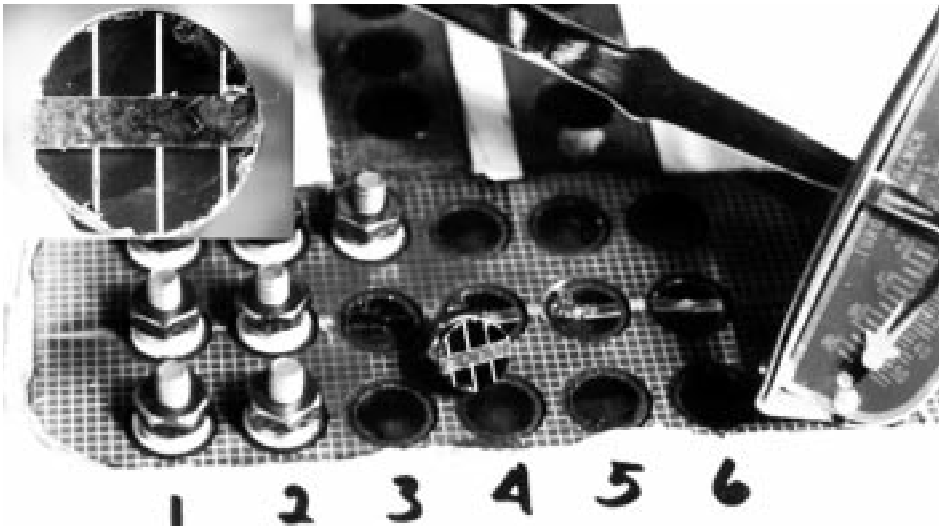


Figure 11. Samples cored and twisted from field-aged modules provide encapsulant adhesion strength measurements, plus samples for solder bond and interface chemistry analyses.

Hot, humid climates have proven to be the most severe in causing encapsulant adhesion failures. After field exposure, phosphorous, solder flux, encapsulant additives, and even sodium that had migrated through the encapsulant from the glass, were examples of reactive materials found at the cell/encapsulant interface. The research conducted at FSEC has also shown that the mechanical properties of the encapsulant such as toughness, Young's modulus, total strain, and ultimate tensile strength also deteriorate most rapidly in hot and humid climates. Additional research will be required to find the combination of materials and manufacturing processes that effectively minimize the loss in encapsulant adhesion with field exposure.

Ultrasonic imaging, similar in concept to that used for prenatal imagery, can be used nondestructively to investigate the internal characteristics of modules (Figure 12). The technique is particularly useful for finding air voids internal to modules that may result from accelerated testing or field exposure. Voids internal to modules provide preferential locations for moisture to accumulate, which can accelerate the degradation of metal contacts or of chemically active layers in some thin-film modules. A similar technique called acoustic microscopy is also being investigated as a means for nondestructively inspecting the quality of solder bonds on the production line and/or following field aging.

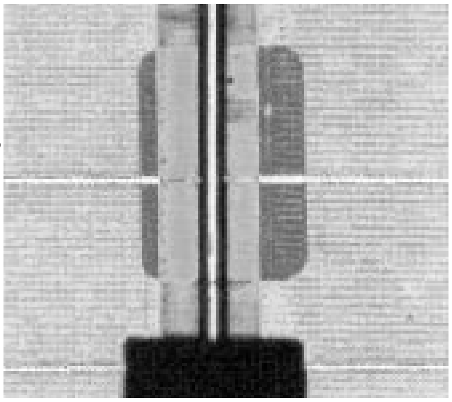


Figure 12. Through-transmission ultrasonic scan of thin-film module. Light regions have high transmission (gaps or solid metal) and dark regions have low transmission (typically air voids). Junction box at bottom, busbar up middle, nameplate label in center.

Moisture Migration in Encapsulant

Moisture migration through module-backing materials and through the encapsulant has commonly been suspected of being involved with the encapsulant browning process and with the chemistry associated with module delamination. However, a method has not been available that quantifies either the rate or the magnitude of moisture migration inside modules. As a result, it is not known whether the moisture migration occurring during accelerated module qualification tests corresponds adequately to the migration process that occurs during outdoor exposure. Capitalizing on research done in other areas at Sandia, a new technique is being investigated. Miniature microelectronic moisture sensors have been developed and used to study moisture migration through a variety of polymeric materials. These sensors are now being adapted and laminated in mini-modules to assess the feasibility of quantifying migration in EVA encapsulant (Figure 13). If successful, these sensors can be laminated inside modules during the manufacturing process and subsequently used to quantify moisture migration rates, during both accelerated aging tests and actual outdoor environmental conditions.

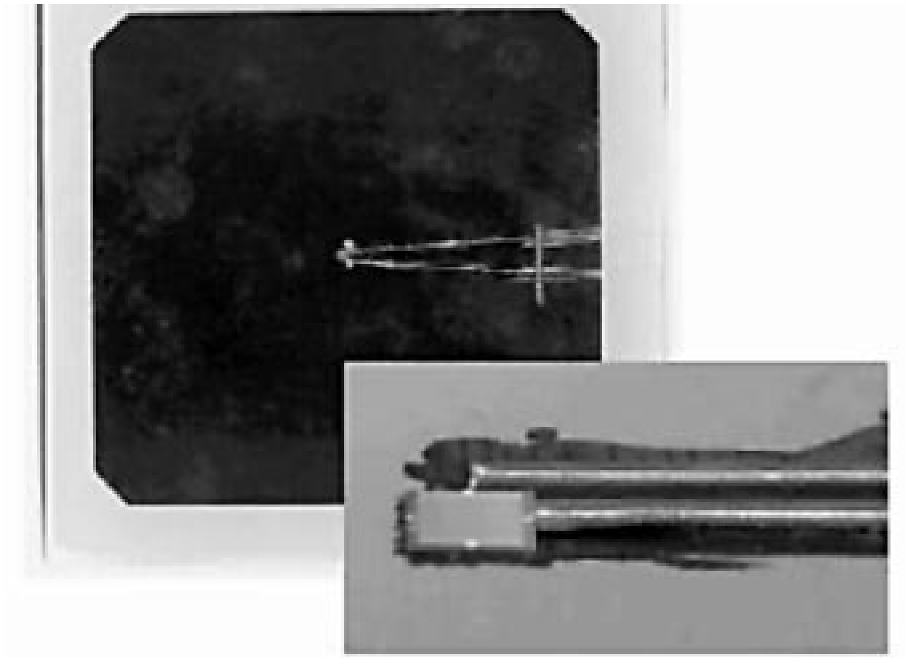


Figure 13. Close-up of moisture sensing semiconductor chip embedded in EVA between silicon cell and glass superstrate.

Evaluation of Factors Influencing Electrical Performance

Series Resistance

Electrical resistance present in wiring, junction-box terminations, cell-interconnect ribbons, cell metallization, emitter and base regions of solar cells, and solder bonds results in voltage losses. These voltage losses limit the performance of a photovoltaic system. Our investigations have indicated that as a system ages, gradual increases in the series resistance components associated only with the module can result in a decline in system power output on the order of 0.5% per year. This rate of performance loss is a significant fraction of the 1 to 2% per year previously documented by others based on long-term monitoring of crystalline-silicon system performance. Cell designers optimize cell designs to minimize series resistance losses, module manufacturers address resistance in cell metallization and soldered interconnects, and system designers attempt to minimize wiring and termination losses. However, the mechanical influences of daily thermal cycling in the field inevitably result in a gradual increase in series resistance as the system ages. Our work has currently focused on the effects of field aging on the solder bonds used to interconnect copper ribbons from cell to cell.

Metallurgical Analysis of Solder Bonds

Destructive test procedures were necessary to visually investigate the effects of field aging on solder bonds. Using the coring procedure previously discussed, solder bond samples were removed from both unexposed and field-aged modules. These samples were potted in epoxy, mechanically polished, and then chemically etched to provide samples for metallurgical analysis. Microscopic investigation of the solder bond cross sections from many samples has provided an improved understanding of the influences of both thermal fatigue and non-optimum manufacturing processes on solder bond integrity (Figure 14). These cross sections have shown a large degree of variability in cell metallization and in solder bond quality in today's commercial modules. Voids, variations in solder thickness and contact area, and irregular cell metallization observed in new modules are believed to contribute to solder bond degradation in the field.

As typical tin/lead solder ages due to continuous thermal cycling outdoors, expansion and contraction causes the solder to fatigue, become more brittle, and disassociate into large grains of tin and lead. This aging phenomenon coupled with manufacturing irregularities results in a propensity for solder bonds to crack, becoming more resistive. As a result of environmental influences, the metallurgical structure of the solder bond continually changes with time (age). A clear result of our investigation is that there is a definite opportunity to improve the production quality of solder bonds in modules. Work to optimize the soldering processes used in production is in progress with individual module manufacturers, again with the goal of achieving 30-year lifetimes. Federal environmental regulations (RCRA, TCLP) and associated disposal costs of products containing lead may also motivate module manufacturers to develop new soldering processes with lead-free solders. The thermal aging characteristics for lead-free solder differ from tin/lead solder, and manufacturing processes will have to be reoptimized for this material.

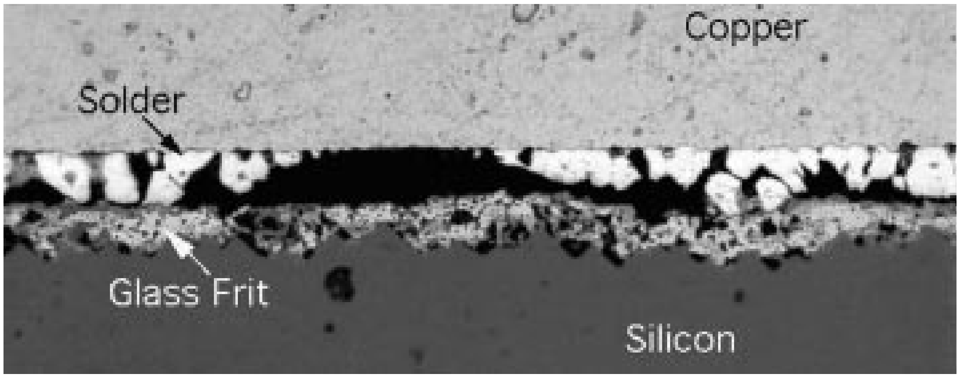


Figure 14. Cross section of solder bond taken from field-aged module showing voids and deterioration in solder layer.

The need for an improved method for monitoring production-quality of solder bonds has also been identified. The integrity of solder bonds has historically been monitored on the production line using a simple mechanical device that measures the force required to peel the soldered interconnect ribbon from a solar cell. This test results in an applied stress that is primarily tensile in nature. A higher "peel" or "pull" strength is typically assumed to indicate a better solder bond. However, this test procedure and this assumption may not be appropriate when the objective is long-term (30-year) fatigue life. For instance, a solder bond may have a high pull strength, but is mechanically brittle and quickly fails by cracking when exposed to thermal cycles. During the repetitive thermal cycles a module undergoes outdoors — perhaps 100,000 cycles in 30 years — thermal expansion produces primarily shear stresses in the solder bonds. Research is in progress to identify a test method related to shear stress and provide a better indicator of thermal fatigue life in solder bonds.

Dark I-V Analysis

System-level power measurements are relatively insensitive to gradual increases in series resistance, due, for instance, to solder-bond cracking. Series resistance in solar cell circuits may have to double in magnitude before a 5% drop in power is realized. Other, more sensitive measurement techniques are available. At the module level, an effective method for quantifying increases in series resistance is the dark current-voltage (dark I-V) measurement in which an electrical power supply is used to generate current flow through the module. This measurement technique is very sensitive to changes in series resistance; changes of 10% can be readily detected. As a result, the method can provide early detection of module degradation mechanisms after a limited time in the field.

Thermal Infrared Imaging

Thermal infrared imaging has provided a convenient and non-destructive means for identifying locations in modules where the series resistance was atypically high. The procedure involves connecting a module to a power supply with the module in a forward-biased condition electrically. The power supply provides a continuous current through the module at a level between one and three times the nameplate short-circuit current. As the module heats up, a digitized image can be recorded showing the temperature distribution in the module. Using this procedure, resistive solder bonds in field-aged modules can be identified as localized hot spots in the image. Figure 15 shows a module with abnormally resistive solder bonds after about six years in the field.

Conclusions

Our investigations of both new and field-aged crystalline-silicon modules have indicated that, in general, today's commercially available modules are highly durable. However, using new test procedures, subtle failure mechanisms have also been identified that must be addressed in order to achieve 30-year module lifetimes. The failure mechanisms being investigated have not been adequately identified by today's accelerated qualification test procedures, indicating a need for improvement in these procedures as well. Research efforts and well-monitored long-term outdoor exposure programs are in progress at Sandia in collaboration with several manufacturers in order to address known reliability issues and to provide early identification of unexpected degradation mechanisms.

(For more information, please contact David King, 505-844-8220, dlking@sandia.gov or Michael Quintana, 505-844-0474, maquint@sandia.gov. The article in this issue of the "Highlights" is based on a paper titled "PV Module Performance and Durability Following Long-Term Field Exposure" that will appear in Progress in Photovoltaics, *Volume 8, No. 2, March-April 2000.)*

Figure 15. Thermal infrared image of 36-cell module with abnormally resistive solder bonds.

BRIEFS

Technology Roadmapping

Report of the PV Technology Roadmapping Workshop, the outcome of an industry workshop held in Chicago in June, is available on the National Center for Photovoltaics website (http://www.nrel.gov/ncpv). It is the next step in creating a blueprint of research, technology, and market priorities needed to accomplish the photovoltaic industry's long-term goals. The roadmapping effort began with a vision statement by the NCPV Advisory Board and a framework document that articulated the photovoltaic industry's goals through 2020. Working from that document, nearly 50 individuals from photovoltaic industry and research institutions met to examine strategic issues for achieving those goals, which this report documents. The National Center for Photovoltaics (Sandia and NREL) co-sponsored the Chicago workshop and continues to facilitate industry's roadmapping efforts.

Conference on Grid-Based Renewable Energy Power Generation

An international conference on Accelerating Grid-Based Renewable Energy Power Generation for a Clean Environment is planned for March 7-8, 2000, in Washington, D.C., at the Lewis Preston Auditorium of the World Bank. Its objective is to promote the acceleration of grid-based renewable energy power generation worldwide. The registration fee is $195 per person. To receive additional information, please fax a request to the conference at 202-682-1682 including name, address and other pertinent information, or e-mail the conference organizers at rec@usea.org. A conference website is located at http://www.worldenergy.org and http://www.USEA.org.

Photovoltaics Website Updates

The latest modification to our website (http://www.sandia.gov/pv) allows a visit to our homepage, a bypass straight to our publications page, or a graphical detour that gives a glimpse of major capabilities and programs. At the Recent Webpage Updates button, we highlight items added over the previous six- or seven-week period. The Publications button reveals all our documents — whether available online or only in hard-copy format. Under the Projects page are brief descriptions of patents granted to Sandia for photovoltaic projects, as well as a description of our licensable intellectual property with links that provide details for doing business with Sandia. The Projects page also lists our work with the Department of Defense.

The Systems Engineering section includes the downloadable paper *Photovoltaic Systems: An End-of-Millennium Review*, which continues to be one of the most frequently accessed writings at Sandia. Another new document is *Photovoltaics for the States*, which summarizes several projects and some lessons learned through that work. Numerous additions have been made recently to the Balance of Systems section, such as Briefs on battery management and surge testing of inverters, and to the solar training programs page, which we developed (with industry participation) to help the Million Solar Roofs program.

Sandia creates and distributes a variety of publications on photovoltaic systems and their applications. For a list of these documents, please contact the Photovoltaic Systems Assistance Center:

through e-mail: pvsac@sandia.gov
by phone: 505-844-3698
by FAX: 505-844-6541

by mail: Photovoltaic Systems Assistance Center
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